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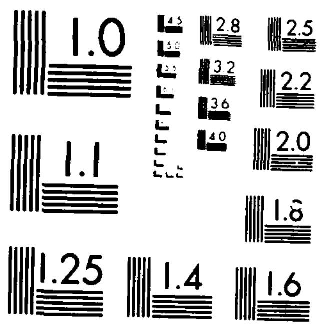
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PROTOTYPE SPATIAL REASONING PROJECT

FINAL REPORT

SAE-DC-86-R-042

January 22, 1986

For

Research Institute Center for Artificial Intelligence
Engineer Topographic Laboratory
U.S. Army
Ft. Belvoir, Virginia

By:

Software Architecture and Engineering, Inc.
1500 Wilson Boulevard, Suite 800
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A demonstration protype system based on expert system technology in which both diagnostic and spatial reasoning techniques can be brought to bear on a problem. The system design allows for the logically different types of reasoning to cooperatively solve classes of problems that have non-spatial and spatial aspects.

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Prototype Spatial Reasoning Project
Final Report

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Jane Potts

January 22, 1986

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Preface

This report represents the last deliverable under CONTRA(
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1. Introduction

1.1. Project Objectives Review

The main objective of the spatial reasoning project, briefly stated, is to:

> Demonstrate the feasibility of using expert system technology as an aid to tactical mission planning and in particular to demonstrate the use of spatial reasoning in this context through a prototype system capable of knowledge-based spatial deduction.

The prototype demonstration addresses a subproblem of tactical mission planning, the determination of likely locations for enemy artillery batteries. This determination is based on various types of supplied and inferred information. The supplied information consists of a symbolic description of the 3-D relationships that are known to exist between the components of an artillery formation (e.g., three artillery batteries not more than 20 meters apart), and other known placement constraints based on the properties of the 3-D object being modeled (e.g, an artillery battery cannot be positioned in a geographic area that contains more than 1 meter of water).

The scope of the enemy artillery battery placement determination is, in the demonstration system, restricted to one possible artillery battery formation and four constraints:

> The formation consists of three distinct artillery batteries that must be in a straight line. The distance between a battery from its immediate neighbor battery can be 2-4 meters inclusive (3 being the optimum) along the X axis, and a +-5 meter difference between battery neighbors (0 being the optimum) along the Z axis.
>
> The absolute difference in elevation between any member of a formation cannot exceed 15 meters.
>
> The distance between the leftmost artillery battery and the rightmost artillery battery contained in the formation must be between 3-24 meters inclusive.
>
> A line of sight must exist between neighboring artillery batteries contained

within the same formation.

The "line" formation must be parallel to the FEBA (Front Edge of the Battle Area) that is defined interactively by the end-user of the demonstration system.

This problem is sufficiently rich to demonstrate the potential of expert system technology and the use of spatial reasoning. (For a more detailed discussion of the problem see "A Prototype Demonstration of Spatial Reasoning as Applied to Army Tactical Planning Problems" SAE document number SAE-DC-83-P-013.)

1.2. Report Organization

The remainder of this report is divided into the following sections:

Status of Tasks - presents a brief account of what has been accomplished relative to the proposed tasks of the project.

Conclusions - presents the general results of the prototype effort and discusses the insights gained into the problem area and recommendations for further work.

Appendices - a collection of information that consists of a description of the deliverables and their location within ETL's VAX 780 file system, instructions on how to invoke and interact with the demonstration system developed, and instructions on how to invoke and interact with a "slide show" of formation placements generated previously through the demonstration system. Also included as an addendum is the BNF developed for the spatial reasoning system.

2. Status of Tasks

There are a number of tasks that were covered under the contract relative to Phase 1 and 2 of the project. Phase 1 tasks were completed and demonstrated to the client at the completion of Phase 1. A discussion of Phase 1 tasks will, therefore, not be addressed here. Phase 2 tasks were as follows:

Complete the demonstration prototype.

Complete spatial expert system, include justification capabilities and domain independent spatial knowledge base parser.

Expand demonstration system to handle multisegment FEBA, sector of interest, side, and bands.

Unfortunately, some of the Phase 2 tasks listed above were not done or totally completed due to insufficient funds. At the beginning of Phase 2 we anticipated that this might happen so we choose to put our effort into those tasks that would still allow a proof of concept for the thesis of the demonstration system, i.e., spatial reasoning. What follows is a discussion of how well we accomplished each of the Phase 2 tasks listed above.

2.1. Demonstration Prototype

The demonstration system prototype is complete. The source code for its various functional components is resident on ETL's VAX 780 file system. The file organization of the source code in an annotated format is presented in Appendix A. The demonstration system is fully functional and can be executed. Instructions on how to run the demonstration system and interact with it is given in Appendix B and C.

2.2. Spatial Expert System

The foundation for the restricted spatial expert system shell proposed is complete and functional. However, due to insufficient funds all of the enhancements to it could not be completed fully and are therefore not operational. All of the code that was produced relative to these enhancements are present on ETL's VAX 780. An enumeration of these enhancements and their present status is presented next.

2.2.1. Justification Capabilities

A very rudimentary justification capability for the spatial reasoner is coded, however, it has not been

integrated into the spatial reasoning system. It would require more work to functionally enchance it so as to be useful and integrate it. Therefore, no justification capabilities relative to the spatial reasoner exist within the demonstration system.

2.2.2. Knowledge Base Parser

A large amount of work went into the development of a domain-independent parser for the spatial reasoner. Both the lexical analyzer and parser are very close to completion. Minor alterations to the lexical analyzer and moderate changes to the parser are required. Also required to complete the knowledge base parser are changes to the internal representational format of the spatial information within the spatial reasoning system. Without these changes the knowledge base parser is only partially operational. The BNF for the syntax developed for the knowledge base parser is given as an addendum to this report.

Since there is no parser available for the spatial reasoning system the information that would normally be contained within it is part of the initialization code of the spatial reasoning code proper. Therefore, in order to change the "knowledge base" used, the initialization code for the spatial reasoner must be changed directly. This code basically performs the same tasks that the parser would perform as side effects. It is important to note that the spatial reasoning system IS domain independent and the fact that the "knowledge base" has to be entered in this unusual manner does not alter this property.

2.3. Expansion of Demonstration System

After completing the work described very little time on the contract remained. None of the demonstration system expansions were performed: multisegment FEBA, sector of interest, side, and bands. However, none of these enchancements are needed to provide the proof of concept sought after.

3. Conclusions

The demonstration system performs its intended task, the placement of artillery battery formations based on spatial constraints and the properties of physical objects. It accomplishes this task by using prototypic spatial inferencing techniques developed by Software A&E personnel.

The correct functioning of this demonstration system represents the proof of concept desired. It has been demonstrated (and therefore proven) that it is possible to infer spatial information by the use of computer-based expert systems.

There are several avenues of research that this prototypic system opens. First, the system is slow. It takes approximately 10-20 minutes to infer placements within a 120 meter squared area. This time can possibly be shortened by developing a more efficient internal representation of the spatial model being worked upon. More research needs to be done in this area. Secondly, the spatial reasoner can be made more powerful by embedding "deep" spatial knowledge within it. A more sophisticated graphically display could be researched and implemented thereby increasing the ease of comprehension for the end-users of such a system.

In conclusion, the fact that it is slow and could be enhanced does not take away from the realization that computer-based spatial reasoning is possible. We have proven it through the existence of the demonstration system developed through this contract.

APPENDIX A

DELIVERABLES ROADMAP

Appendix A: Deliverables Roadmap

The following is a roadmap to the contract deliverables. Names that are underlined represent directories, names indented under these directories are the files/directories contained within them

D E L I V E R

demo-run
        executable for a demostration run of the spatial reasoning system
feba_data
        temporary file created by demo (gs) - contains endpoints of feba
filename.tmp
        temporary file created by demo (gs) - contains name of image file
gs
        graphics executable called by spatial reasoning system
gs-parameters
        temporary file created by demo (ses)
gscoords
        temporary file created by demo (gs) - coordinates of center point of
        area of interest
positions_data
        temporary file created by demo (ses) - artillary placements determined
        by the spatial reasoning system
primary.elev
        temporary file created by demo (gs) - image file of elevation for
        display on the grinnell created from the raw data of the catts data
primary.hydro
        temporary file created by demo (gs) - image file of hydrography for
        display on the grinnell created from the raw data of the catts data
r_positions
        temporary file created by demo (ses) - ?
ses
        executable of the spatial reasoning system
spatial-demo.kb
        the KES.PS knowledge base that controls the operation
        of the demonstration system
subarea_data
        temporary file created by demo (gs) - contains coordinates, elevation,
        and hydrography of each pixel in the subarea of interest

COMMON:

directory contains the source code common to both the Shared Information System and original Graphics system. These source files have been replaced with an enhanced version of the system. They are no longer needed and are present soley to give the client all the code developed under the contract.

```
   dbio.h
   list.h
   sis.h
   sisint.c

KES:
----
   directory contains enhancements to KES 1.4.3 for use with the
   spatial reasoning system

   Ecntrl1.l
        control functions
   Econclude.l
        conclude functions
   Eexternal.l
        external functions
   Egetargs.l
        get arguments functions
   Ehelp.l
        help functions
   Enassert.l
        assert functions (cassert implemented)
   Enstop.l
        stop functions (sx implemented)
   Eps.o
        relocatable code of modified kes.ps
   Estatus.l
        status functions
   Estmt.l
        statement functions
   Makefile
        Makefile to generate Eps.o and modified kes.ps
   modified-kes.ps
        executable of modified kes.ps

NEW-GRAPHICS:
-------------
   directory contains the source code and executable of the enhanced
   graphics system that is called by the spatial reasoning system

   Makegraphics
        Makefile to create gs, the graphics executable used by the
        spatial reasoning system
   getcatval.c
        c file included in gfuns.c which gets values from the catts
        raw data
   gfuns.c
        c source file for gs, the graphics system.  Includes cursor routines
        written specifically for the project
   gfuns.c,v
        archived (rcs) gfuns.c
   gpconstants.h
        included by gfuns.c, contains constant graphics declarations
```

gs
    executable of the graphics program called by the spatial reasoning system

NEW-GRAPHICS/TESTING:
----
    subdirectory for running tests of the graphics system

    feba_data
        temporary file created by gs - contains endpoints of feba
    filename.tmp
        temporary file created by gs - contains name of image file
    gs-parameters
        temporary file created by ses
    gscoords
        temporary file created by gs - coordinates of center point of area of interest
    positions_data
        temporary file created ses - artillary placements determined by the spatial reasoning system
    primary.elev
        temporary file created by gs - image file of elevation for display on the grinnell created from the raw data of the catts data
    primary.hydro
        temporary file created by gs - image file of hydrography for display on the grinnell created from the raw data of the catts data
    subarea_data
        temporary file created by gs - contains coordinates, elevation, and hydrography of each pixel in the subarea of interest

OLD-GRAPHICS:
----
    old graphics code for earlier version

    GSgetcatimg.c
        included in gpfcns.c, get raw catts data
    Makefile
        make test relocatable, gtest.o
    READ.ME
        readme file
    gchar.c
        included in gscaller.c, get character routine
    gchar.h
        included in gchar.c, get character definitions
    getcatval.c
        included in gpfcns.c, c file which gets values from the catts raw data
    gpconstants.h
        included in gpfcns.c, contains constant graphics declarations
    gpfcns.c
        c file to make old graphics system
    gpfcns.h
        included in gpfcns.c, contains graphics functions
    graphics.doc

```
        documentation of old graphics
    gscaller.c
        c source file of calling routine of old graphics system
    gscaller.o
        relocatable of calling routine of old graphics system
    gtest.c
        graphics test source code file
    int_gs.l
        lisp graphics initializer and loader source file
    int_gs.o
        lisp graphics initializer and loader relocatable
    shading.c
        included in gpfcns.c, c source file for shading
    test.c
        test graphics system
    test2.c
        test graphics system
```

NEW-SES:

```
    new spatial reasoning system

    ETL-main.l
        lisp source code main caller file
    ETL-main.o
        lisp relocatable main caller file
    READ.ME
        readme for new spatial system
    SES
        executable of new spatial system
    angles.l
        lisp source files concerning angles
    angles.o
        lisp relocatable files concerning angles
    begin.l
        lisp source files to create the standalone
        spatial reasoning system used in the
        demonstration system.
    commands.l
        lisp source files concerning commands
    commands.o
        lisp relocatable files concerning commands
    compile.l
        lisp source files concerning compilation
    cstack.l
        lisp source files concerning command stack
    cstack.o
        lisp relocatable files concerning command stack
    ext_file.l
        lisp source files concerning externals
    ext_file.o
        lisp relocatable files concerning externals
    format.l
```

```
     lisp source files concerning format
globals.l
     lisp source files concerning format
globals.o
     lisp relocatable files concerning globals
info_space.l
     lisp source files concerning globals
info_space.o
     lisp relocatable files concerning information space of system
parse.l
     lisp source files concerning command parser of system
parse.o
     lisp relocatable files concerning command parser of system
sys.l
     lisp source files concerning system
sys.o
     lisp relocatable files concerning system
wksp_space.l
     lisp source files concerning work space of system
wksp_space.o
     lisp relocatable files concerning work space of system
```

NEW-SES/PARSER:

```
     files and directories necessary to create the parser, and to invoke
     lisp functions acting upon parsed objects

     Makeparser
        Makefile to make the parser  invokes yacc and lex as well as the
        c compiler, plus some special utilities necessary to the interface
        between lisp and c
     callparse.l
        lisp file that calls the c relocatable of the parser
     justify.l
        lisp functions for justification of placement of objects by the
        spatial system
     main.l
        lisp source main for sample parser
     main.o
        lisp relocatable main for sample parser
     model.l
        lisp functions for initial model instantiation
     spatial-kb1
        sample kb for the parser
     startfuns.l
        lisp startup functions loaded before calling the parser
     startup.l
        startup file to load lisp files and the parser
     template.l
        lisp functions for templates (used by justification ad
             initial models)

     PARSER/data:
```

----

test data files to test the different sections of the parser created for the spatial system - must be concatenated together to create one data file :

```
cat con.dat prim.dat obj.dat init.dat com.dat > test.dat
```

com.dat
    commands section
con.dat
    constants section
init.dat
    initial models section
l1.dat
    sample test data file
obj.dat
    application objects section
prim.dat
    user primitives section

PARSER/defs:
----

definition file(s) for the parser

y.tab.h
    definition file for the parser and lexical analyzer generated by yacc

PARSER/doc:
----

documentation concerning lisp and the lisp-c interface

Lisp_C.doc
    interface between lisp and c, written by J. K. Potts
franz.doc
    description of lisp on the vax by John Foderaro

PARSER/interm:
----

intermediate c files generated by lex and yacc

lex.yy.c
    c file generated by lex for lexical analyzer of the spatial system
y.tab.c
    c file generated by yacc for parser of the spatial system

PARSER/reloc:
----

relocatables for lexical analyzer and parser

lex.yy.o
    relocatable for lexical analyzer, generated by lex
spatial.o

```
                relocatable for spatial system parser, lexical analyzer
                and parser linked together and called from lisp
           y.tab.o
                relocatable for parser, generated by yacc

        session.dat
           sample session of the parser called from lisp

        PARSER/source:
        --------------
           source code for parser and lexical analyzer

           lxspatial.c
                c source file for lexical analyzer - input to lex
           lxspatial.c,v
                archived (rcs) lxspatial.c
           objclass.l
                lisp functions for displaying object classes
           savesp.y
                earlier version of c source file for parser - input to yacc
           spatial.y
                c source file for parser - input to yacc
           spatial.y,v
                archived (rcs) spatial.y

    NEW-SES/TESTING:
    ----------------
        contains versions of ETL-main.l that were
        used in testing of the demonstration system
        along with needed data files.

        ETL.l
        ETL2.l
        feba_data
        fulda.gen
        positions_data
        r_positions
        subarea_data

OLD-KBS:
--------
   knowledge bases that drove the old spatial system

   des.kb
        decision supervisory system
   ipses.kb
        interface protocol system

   OLD-KBS/testkbs:
   ----------------
        test knowledge bases to ascertain the
        correctness of the modified KES.PS system
        developed for this contract
```

```
      testblock
      testkb
```

OLD-SIS:
----

directory contains the source code for the
Shared Information System. These source
files have been replaced with an enhanced
version of the system. They are no longer needed and
are present soley to give the client all the code
developed under the contract.

```
Makefile
sisex.c
```

SLIDE-SHOW:
----

sample sessions of the spatial system for demonstration.
Includes the saved data files from previous sessions
so that they can be presented during the execution of slide-show.

```
x_feba_data
x_filename.tmp
x_gscoords
```

APPENDIX B

HOW TO USE THE DEMO

Appendix B: How to Use the Demo

Very simple. Change your directory so that your present working directory is "/etl/other/barryp/deliver":

```
cd /etl/other/barryp/deliver
```

Enter the command "demo-run" and then follow the directions presented to you on the screen. The system is very easy to use and there is a tutorial built into tha system. The oppurtunity to view this tutorial will be offered to you as a choice to the first system generated question to you.

APPENDIX C

HOW TO USE THE SLIDE SHOW

Appendix C: How to Use the SLIDE SHOW

Very simple. Change your directory so that your present working directory is "/etl/other/barryp/deliver":

```
cd /etl/other/barryp/deliver
```

Enter the command 'slide-run' and then follow the directions presented to you on the screen.

APPENDIX D

GRAPHICS MODULE

Appendix D: Graphics Module

GS - The Graphics Module

FUNCTION

This module provides the use of the graphic capabilities of the grinnell to the spatial system. A catts raw data set for a 512 by 512 image is processed to produce two image files: one for elevation of the area; one for the hydrography of the area. The user is asked to define a FEBA (forward edge of the battle field) and a subarea of interest (the latter is an 11 X 11 pixel square). The results of the spatial reasoning system may be displayed on the grinnell.

The gs program is called by the spatial system in one of three modes :

- image : creates the image file for display on the grinnell from the raw catts data, then prompts the user to desigate the feba and the area of interest
- reuse : uses the existing image file, created by an earlier call to gs, and prompts the user to designate the feba and the area of interest
- placements : displays placements determined by the spatial reasoning system

PARAMETERS

The valid parameters to the gs program are:

```
gs image <catts raw data> <input parameters file>
gs reuse
gs placements <name of placements file>
```

INPUT FILES

The files needed by the graphics module are (<> indicates command line parameters):

```
for image:
    </imgg/catts/fulda/rawdata/fulda.512> - raw catts data
    <gs-parameters> - x and y coordinates of lower left corner
for reuse:
    primary.elev - image file of elevation
    primary.hydro - image file of hydrography
for placements:
    primary.elev - image file of elevation
    primary.hydro - image file of hydrography
```

```
<positions_data> - 3-point coordinate data
feba_data - feba endpoints
gscoords - coordinates of center of area of interest
```

OUTPUT FILES

The files generated by the graphics system are:

```
    by image:
        primary.elev - image file of elevation
        primary.hydro - image file of hydrography
        feba_data - feba endpoints
        gscoords - coordinates of center of area of interest
        subarea_data - coordinates, elevation and hydrography of
                points in subarea of interest
        filename.tmp - file containing name of image file created
    by reuse:
        feba_data - feba endpoints
        gscoords - coordinates of center of area of interest
        subarea_data - coordinates, elevation and hydrography of
                points in subarea of interest
        filename.tmp - file containing name of image file created
    by placements:
        none
```

COMPILATION

A Makefile called Makegraphics will provide all the necessary linking to be done to produce the executable:

```
# Home directories.
ROOT = /iu/tb

# Library archives.
LIB = $(ROOT)/lib
VSNLIB = $(LIB)/visionlib.a
CMULIB = $(LIB)/cmuimglib.a
SUBLIB = $(LIB)/sublib.a
IMGLIB = $(LIB)/imagelib.a

gs: gfuns.c
        cc -g gfuns.c  $(VSNLIB) $(CMULIB) $(IMGLIB) $(SUBLIB) -lm
        mv a.out gs
```

FUNCTIONS

A brief description of the internal functions of the graphics module follows:

GSgetcatimg   Read raw catts data file and convert to image file

box_point	draws red overlay box around x and y point with side length of len, and returns 2 sets of x and y coordinates that define the box
check_coords	checks that feba points are on valid sides
create_img_file	Create image file from raw catts data -- calls GSgetcatimg
define_feba	Routine for defining feba
display_results	displays results of spatial system in right hand corner of grinnell
display_x_y	updates display of x, y and step values of grinnel cursor in lower right corner of grinnel screen
error_usage	Prints error message about usage of gs program
expand	expands the area of source frame (img) defined by x1, y1, x2, y2 and writes to upper right hand corner of destination frame
g_kcur	Keyboard cursor routine
get_cursor	gets cursor position maxpoints times, storing x and y positions in xarray and yarray
get_feba	Put up image frame and obtain feba
main	determines mode (image, reuse, display) and call appropriate subroutines
num_to_string	converts integer to string
print_file_coords	Prints xyz coordinates in kes format
raw_read	reads one raw input character from keyboard -- does not echo to output
translate_coords	Translates a point with coordinates x, y from origin x_offset, y_offset to origin x_origin, y_origin, with an expansion factor (factor == 1 will give a direct mapping)

APPENDIX E

KNOWLEDGE BASE PARSER

Appendix E: Knowledge Base Parser

PARSER - the yacc parser of the spatial system

FUNCTION

The parser parses an input data file in order to store data in the lisp system. In addition to syntactic error checking, the parser builds lisp objects given syntacticly and semanticly correct data. These objects are to serve as data for the spatial reasoning system.

The parser of the spatial system is a c function that may be called from lisp. The c function in turn calls yyparse(), a unix system-defined function name that invokes a yacc program, written in the yacc language. The yacc language produces a lr(1) parser. The yacc program makes use of a lexical analyzer written in lex. The parser requires as input a file of data whose syntax conforms to the grammar described by the SPATIAL 1.0 Grammar by Barry T. Perricone (Software A & E Confidential), dated August 16, 1985. As the parser parses the input data, certain information is stored in the lisp system that will be operated upon by the spatial reasoning system.

INPUT FILES

The parser expects an input file from which it will read data. The name of the input file is a parameter to the parser.

OUTPUT FILES

None.

COMPILATION

A Makefile, Makeparser, will invoke lex (for the lexical analyzer), yacc (for the parser), and perform the special kind of c compilation needed for a function that will call lisp from c (see Lisp_C.doc for an explanation of the c compilation needed). Certain files resident on the vax are needed for the lisp-c interface. These files currently reside on the ETL vax-780 in /src/usr/ucb/lisp/franx/h and /src/usr/ucb/lisp/franx/vax. Once compiled, the parser may be loaded into the lisp system by the cfasl command:

```
(cfasl '../../reloc/spatial.o '_call_yyparse 'callparser "integer function")
```

DIRECTORY STRUCTURE

The following directories pertain to the parser:

NEW-SES/PARSER

Top-level dierctory, containing the Makefile (Makeparser), and some of the auxiliary lisp files used for justification and display of instantiated lisp objects

data
: data files (if any) for the parser

defs
: contains y.tab.h, definition file created by yacc

doc
: documentation, Lisp_C.doc (the lisp-c interface), and franz.doc (description of franz lisp by John Foderaro)

interm
: contains intermediate files produced by lex (lex.yy.c), yacc (y.tab.c)

reloc
: contains relocatables produced by lex (lex.yy.o), yacc (y.tab.o), and the c compiler (spatial.o, the parser in final relocatable form)

source
: source code for yacc (spatial.y, and its archive, spatial.y,v), lex (lxspatial.c, and its archive, lxspatial.c,v)

DOCUMENTS

Essential to the understanding of the parser is the description of the grammar in BNF form as described in the SPATIAL 1.0 Grammar by Barry T. Perricone, dated August 16, 1985 (Software A & E Confidential). Since the parser builds lisp objects, an understanding of the lisp-c interface is essential, and is described in the Lisp_C.doc document written by J. K. Potts (Software A & E).

FUNCTIONS

The following is a list of internal functions in the yacc program with brief descriptions:

add_feature	adds feature to the current instatnitation of an object
add_prim_list	adds gensym to *usr_prim_list*
add_value	adds value to the current instatnitation of an object
call_yyparse	the c invoked by lisp function that calls the parser
clean_up_var	clean up variables
command_parse	parses command
complete_model	completes the slots of an instantiation

free_nameptr	frees the storage allocated to a nameptr variable
get_atom_value	gets actual lisp value of an atom, given its pname (pname is a printable string)
get_feature	gets feature slot of the named object
get_operator	gets lisp value of string representing operators such as "le", "gt", etc.
get_slot_val	gets slot value of a given slot for the named object
hashy	returns a hash code index for a string
init_var	initialize variables
install	installs a string, its object definition, discipline and nameptr in the hashtable
install_slot	installs slot value of a given slot for the current gensym
lisp_print	prints any type of valid lisp object
locate_name	calls Dinfo_manage with 'locate parameter in order to locate a lisp object indexed by its name lisp name (a list of atoms representing its name)
lookup	Looks up a string in the hash table. If not there, returns NULL. Otherwise, returns pointer to hash table data object
make_gensym	makes a gensym
make_lisp_name	makes a lisp name (a list of atoms) out of a nameptr variable
make_name_sym	calls Dmksym with an indexing letter (e.g, 'U. 'C)
make_sym	calls Dmksym with no indexing letter (i.e., 'U, 'C)
namecopy	makes a nameptr copy of a nameptr variable
newstrcat	concatenates two strings, inserting a space between them
prim_parent	finds parent of primitive (or application object) and stores in parent slot of current gensym
print_hash_table	prints information about constants, primitives, application objects, and initial models that have been parsed

retrieve_slot	retreives a slot for the named object
set_feature	sets feature
set_sym	sets the input gsym to the given value
store_constant	stores constant, its type and value in the lisp system. It calls Dmksym and Dinfo_manage
strsave	returns a fresh copy of string
yyerror	yyerror prints out errors encountered during parsing

ADDENDA

SPATIAL 1.0 GRAMMAR (BNF FORM)

Spatial 1.0 Grammar (BNF Form)

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Table of Contents

Introduction

Notation Conventions

[N]	Non-terminal symbol
(N)	optional single occurence of N
'N'	Literal symbol
"N"	String constant
N^+	1 or more occurences of N
N^*	0 or more occurences of N
$N_{[x,y]}$	minimum occurences of N is x; maximum is y
|	seperates alternative syntactical structures. This BNF connector is weaker than a sequence of non-terminal and/or terminal symbols.
N • M	exclude from the expansion of the non-terminal N the expansions that are possible through the non-terminal M
E	represents the empty termination of a non-terminal
(N)	denotes the grouping of the syntactical element for a logical syntactical structure.
N	comment

There can be zero or more occurences of "seperators" between the syntactical structures of the grammar. "Seperators" are not explicitly accounted for within the grammar unless it is important to account for them, in which case it will be noted within the grammar. Multiple occurences of a "seperator" are considered to be a single occurence of the given "seperator". Characters considered to be in the class of "seperators" are: blank space, tab, newline, and carriage return.

Comment Syntax for Spatial 1.0 Knowledge Base

The comment character for the Spatial 1.0 system described in this document is the backslash character(i.e., '\'). Any text on the same line following the backslash character is ignored by the system.

• MAIN SPATIAL KNOWLEDGE BASE SECTIONS (**MAIN**)

[spatial_kb] ::= ([constants]) [spatial_schemas] ([initial_model])
    [commands]

[constants] ::= 'constants' ':' [**CNST**.constant_dcl] (';' [**CNST**.constant_dcl])* '%'

[spatial_schemas] ::= ('user' 'primitives' ':'
    [**SCHEMA**.prim_dcl] (';' [**SCHEMA**.prim_dcl])* '%')
    'application' 'objects' ':'
    [**SCHEMA**.obj_dcl] (';' [**SCHEMA**.obj_dcl])* '%'

[initial_model] ::= 'initial' 'model' ':'
    [**MODEL**.model_dcl] (';'[**MODEL**.model_dcl])* '%'

[commands] ::= 'actions' ':' [**CMDS**.cmd_dcl] (';' [**CMDS**.cmd_dcl])* '%'

• CONSTANTS SECTION (**CNST**)

[constant_dcl] ::= [name] [constant_type]

[constant_type] ::= '(' ('string' ')' ':' [string]) |
    'integer' ')' ':' ([unsigned_int] | [signed_int]))

• SPATIAL SCHEMAS (**SCHEMA**)

primitive object schemas

[prim_dcl] ::= [**NM**.name] '('
    ('block' ')' ':' [pblock] |
    'point' ')' ':' [features] |
    'line' ')' ':' [features] |
    [**SEM**.prim_nm] ')' ':' [**SEM**.legal_dcl])

[pblock] ::= [features] ([height]) ([width]) ([length]) |
    [height] ([width]) ([length]) |
    [width] ([length]) |
    [length]

application object schemas

[obj_dcl] ::= [**NM**.name] [obj_type]

◇ [obj_type] ::= '(' ([setof] | [not_setof])

◇ [not_setof] ::- ('block' ')' ':' [block_dcl] |
'point' ')' ':' [point_dcl] |
'line' ')' ':' [line_dcl] |
'conceptual' ')' ':' [conceptual_dcl] |
[**SEM**.prim_nm] ')' ':' [**SEM**.legal_dcl] |
[**SEM**.obj_nm] ')' ':' [**SEM**.legal_dcl])

◇ [setof] ::- 'setof'
('block' ')' (':' [block_dcl]) |
'point' ')' (':' [point_dcl]) |
'line' ')' (':' [line_dcl]) |
'conceptual' ')' (':' [conceptual_dcl]) |
[**SEM**.prim_nm] ')' (':' [**SEM**.legal_dcl]) |
[**SEM**.obj_nm] ')' (':' [**SEM**.legal_dcl]))

◇ [block_dcl] ::- [features] ([height]) ([width]) ([length]) ([origin]) |
[height] ([width]) ([length]) ([origin]) |
[width] ([length]) ([origin]) |
[length] ([origin]) |
[origin]

◇ [origin] ::- '[' 'origin' ':' 'atop' '[' 'class' ':' [obj_nm] ']'
('[' 'constraints' ':'
([**SEM**.num_feature_nm] [num_rel] [**NUM**.int_ref] |
[**SEM**.str_feature_nm] [eq_rel] [**NM**.str_ref]) ']')) ']'

****
*** *NOTE: Only one constraint allowed here. For more general*
*** case later must be one or more.
****

[height] ::- '[' 'height' ':' [**NUM**.pos_int_ref] ']'

[width] ::- '[' 'width' ':' [**NUM**.pos_int_ref] ']'

[length] ::- '[' 'length' ':' [**NUM**.pos_int_ref] ']'

[features] ::- '[' 'features' ':' ('[' [**NM**.name] [feature_type] ']')* ']'

◇ [feature_type] ::- '(' ('string' ')' (':' [**NM**.str_ref]) |
'integer' ')' (':' [**NUM**.int_ref]))

[point_dcl] ::- ([features]) [origin] | [features] ([origin])

[line_dcl] ::- ([features]) [origin] | [features] ([origin])

conceptual schema type

[conceptual_dcl] ::- [consists_of] [topology] [relative_origin]
([structural_constraints]) ([orientation])

[consists_of] ::- '[' 'consists' 'of' ':' [consists_nm] (';' [consists_nm])* ']'

[consists_nm] ::- [name] '(' [prim_nm] | 'block' | 'point' | 'line') ')'

[topology] ::= '[' 'topology' ':' [top_dcl] (';' [top_dcl])* ']'

[top_dcl] ::= [**NM**.cof_nm]$_1$ ',' [**NM**.cof_nm]$_2$ [binary_tolerance]
([binary_constraints])

****
*** [**NM**.cof_nm]$_1$ * [**NM**.cof_nm]$_2$
*** [**NM**.cof_nm]$_1$, [**NM**.cof_nm]$_2$ must be declared within the
*** [consists_of] expansion [topology] is associated with
****

[relative_origin] ::= '[' 'relative' 'origin' ':' [**NM**.cof_nm] ']'

[binary_tolerance] ::= '[' 'tolerance' ':' '[' 'x' ':' [min_max] ']'
'[' 'y' ':' [min_max] ']'
'[' 'z' ':' [min_max] ']' ']'

****
*** tolerance between difference in (x y z)$_1$ of [**NM**.cof_nm]$_1$
*** and (x y z)$_2$ of [**NM**.cof_nm]$_2$
****

```
[min_max]          ::= '(' ( [NUM.int_ref]1 ',' [NUM.int_ref]2 | [NUM.zero] ) ')'

                   ***********************************************
                   *** [int_ref]1 <= [int_ref]2
                   ***********************************************

[binary_constraints]::= '[' 'constraints' ':' [ln_projection] ']'

[ln_projection]    ::= 'line' 'projection' '=' ( 'true' | 'false' )

[orientation]      ::= '[' 'orientation' ':' 'parallel' 'to' [SEM.line_nm] ']'

[structural_constraints]::= '[' 'conceptual' 'constraints' ':'
                        ( [elevation] | [distance] )+ ']'

[elevation]        ::= '[' 'maximum 'elevation' 'difference' ':'
                   [NM.cof_nm] ( ',' [NM.cof_nm][2,N] [NUM.pos_int_ref] ']'

                   ***********************************************
                   *** where N is the number of identifiers (i.e., [consists_nm]
                   *** expansions)  generated through the [consists_of]
                   *** expansion ass/w [elevation]
                   ***********************************************

[distance]         ::= '[' 'distance' '(' ( 'x' (',' 'y') (',' 'z') | 'y' (',' 'z') | 'z' ) ')' ':'
                   [NM.cof_nm] ( ',' [NM.cof_nm][2,N] [NUM.pos_int_ref] ']'

                   ***********************************************
                   *** where N is the number of identifiers (i.e., [consists_nm]
                   *** expansions)  generated through the [consists_of]
                   *** expansion ass/w [distance]
                   ***********************************************
```

coordinates

```
[endpoint]         ::= '[' 'endpoint' ':' [coordinate] ']'

[coordinate]       ::= 'x'  ':=' [NUM.pos_int_ref] ','
                       'y'  ':=' [NUM.pos_int_ref] ','
                       'z'  ':=' [NUM.pos_int_ref]
```

relations

```
[num_rel]          ::= 'le' | 'ge' | 'lt' | 'gt' | [eq_rel]

[eq_rel]           ::= '=' | '#'
```

• INITIAL MODEL DECLARATION (**MODEL**)

```
[model_dcl]       ::= '[' ( ( [SEM.ablock_nm] | [SEM.aline_nm] |
                             [SEM.aconceptual_nm] ) [f_assign] [o_assign]  |
                           [SEM.apoint_nm] [f_assign] [o_assign] [SCHEMA.endpoint] )
                      ']'

[f_assign]        ::= '[' 'features' ':' [feature_stmnt] ( ';' [feature_stmnt] )* ']'

[feature_stmnt]   ::= [SEM.feature_nm] '=' [SEM.legal_val]

[o_assign]        ::= '[' 'origin' ':' [SCHEMA.coordinate] ']'
```

• COMMANDS (CMDS)

```
[cmd_dcl]        ::= 'lastmark' | 'mark' | 'rdcommand' [NM.file_nm] |
                     'obtain' [SEM.obj_nm] ([obtain_opts]) |
                     'justify' [j_opts]

◇ [j_opts]       ::= [obj_nm] ('=' '(' [NUM.unsigned_int]1
                     [NUM.unsigned_int]2 [NUM.unsigned_int]3 ')' )

                     ****************************************
                     *** where:
                     ***
                     ***  [NUM.unsigned_int]1 --- x origin coordinate
                     ***  [NUM.unsigned_int]2 --- y origin coordinate
                     ***  [NUM.unsigned_int]3 --- z origin coordinate
                     ****************************************

[obtain_opts]    ::= 'within'  [boundary]

[boundary]       ::= 'boundary' '(' ( '[' [SCHEMA.coordinate] ']' )[3,30] ')'
```

• NAMES (**NM**)

[str_ref]	::= [string] | [**SEM** strc_nm]
[file_nm]	::= [letter] [file_end]
[name]	::= [word] ([seperator]$^{+}$ [word])^{4}
	************************ *** all [name] s are unique ************************
[string]	::= a sequence of characters bracketed by double quote character (i.e., ' " ') that does not extend over a newline or carriage return
[word]	::= [letter] ([word_end])
[word_end]	::= [digit] | [letter] | '_' ([letter] | [digit])$^{+}$
[file_end]	::= [word_end] | '.' [word_end]
[letter]	::= A-Z | a-z
[digit]	::= 0-9
[seperator]	::= blank space | tab | newline | carriage return

NUMERICS (**NUM**)

```
****************************************************************
*** all integers generated (e.g., [unsigned_int], [signed_int], [pos_int_ref], etc.)
*** must be in the range specified by [default-int]
****************************************************************
```

[default_int] ::= the range of integers that are supported by the host computer

[unsigned_int] ::= [**NM**.digit]$^+$

[signed_int] ::= ('-') [**NM**.digit]$^+$

[int_ref] ::= [unsigned_int] | [signed_int] | [intc_nm]

[pos_int_ref] ::= [unsigned_int] | [intc_nm]

```
************************************************
*** if expanded to [intc_nm] then [intc_nm] must reference
*** a POSITIVE integer
************************************************
```

[zero] ::= the [digit] 0

NAMING SEMANTICS (SEM)

[strc_nm] ::= a unique [**NM** name] used within a [**CNST** constant_dcl] expansion to a string type constant

[intc_nm] ::= a unique [**NM** name] used within a [**CNST** constant_dcl] expansion to a integer type constant

[obj_nm] ::= a unique [**NM** name] that was used in an [**SCHEMA** obj_dcl] expansion

[prim_nm] ::= a unique [**NM** name] that was used in an [**SCHEMA** prim_dcl] expansion

[cof_nm] ::= a [**NM** name] expanded from within a [**SCHEMA** consists_nm] expansion

[line_nm] ::= a [**NM** name] that references a LINE-typed object or a descendent of a LINE-typed object.

[ablock_nm] ::= a [**NM** name] that references a BLOCK-typed [obj_nm] or a descendent of a BLOCK-typed [obj_nm].

[aline_nm] ::= a [**NM** name] that references a a LINE-typed [obj_nm] or a descendent of a LINE-typed [obj_nm].

[aconceptual_nm] ::= a [**NM** name] that references a a CONCEPTUAL-typed [obj-nm] or a descendent of a CONCEPTUAL-typed [obj_nm].

[apoint_nm] ::= a [**NM** name] that references a a POINT-typed [obj_nm] or a descendent of a POINT-typed [obj_nm].

[num_feature_nm] ::= a unique [**NM** name] used within a [**SCHEMA** features_dcl] expansion to declare a feature of [**SCHEMA** features_type] 'integer'

[str_feature_nm] ::= a unique [**NM** name] used within a [**SCHEMA** features_dcl] expansion to declare a feature of [**SCHEMA** features_type] 'string'

[legal_dcl] ::= a legal declaration expansion for the primitive type of the [name] it is associated with. (association may be through an "ancestor" of the [name]).

END

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